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The trial context determines adjusted localization of stimuli: reconciling the Fröhlich and onset repulsion effects

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Abstract

It is known that observers make localization errors in the direction of motion when asked to localize the perceived onset position of a moving target (Fröhlich effect). However, recent studies also revealed the contrary: In the onset repulsion effect, the error is opposite to the direction of motion. In four experiments we demonstrate that the conflict between these findings is resolved by considering the trial context: when the stimuli appeared at predictable positions to the left or right of fixation, pointing responses to the perceived onset position were displaced in movement direction. In contrast, when the stimuli appeared at unpredictable positions in the visual field, pointing errors were displaced opposite to motion or at least drastically reduced. Thus, localization of the perceived onset position varies with the trial context.
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When observers are asked to localize the perceived onset position of a moving target, they typically make localization errors in the direction of motion. This localization error was discovered in the first half of the last century and is referred to as Fröhlich illusion. Originally attributed to the so-called "Empfindungszeit" (i.e. the time needed to generate the sensation of a stimulus, Fröhlich, 1923, see also Kreegipuu & Allik, 2003), the illusion is nowadays explained by various-partly contradictory-accounts including attentional mechanisms, priming, or extrapolation of target positions (see e.g. Aschersleben & Müsseler, 1999; Kerzel & Müsseler, 2002; Kirschfeld & Kammer, 1999; Müsseler & Neumann, 1992; Nijhawan, 2002; Whitney, Cavanagh, & Murakami, 2000).

All of these interpretations were concerned with explaining mislocalization in the direction of motion, however, recent studies also confirmed the reverse error. In the onset repulsion effect (ORE), the targets' onset is consistently mislocalized opposite to motion (Fig. 1(a); Thornton, 2002; see also Actis-Grosso & Stucchi, 2003; Hubbard & Motes, 2002; Kerzel, 2002; Kerzel & Gegenfurtner, 2004). An increase in stimulus velocity accentuates this difference: While the backward error (opposite to motion) increased with increasing stimulus velocity in the ORE (Thornton, 2002), the forward error (in the direction of motion) also increased with increasing velocity in the Fröhlich illusion. So far, both illusions were not observed within a single experiment and the discrepancy between both effects has not been resolved.

The present paper aimed to reconcile the Fröhlich effect and ORE. Analysis of the stimulus conditions in previous studies shows that the predictability of target onset positions differed strongly (cf. Thornton, 2002). For example, in order to replicate the original Fröhlich effect, Müsseler and Aschersleben (1998) used only linear, left- or rightward target motion. To control for target eccentricity, the target onset was always at a constant eccentricity to the left or right of fixation. That is, there were only two narrow regions of space in which the target could appear such that target onset position was highly predictable. In contrast, ORE was observed when target onset positions were completely unpredictable. For example, in the study of Thornton (2002; see also Hubbard & Motes, 2002; Kerzel & Gegenfurtner, 2004) the targets' onset was random within a larger square field. Additionally, target motion could be in one

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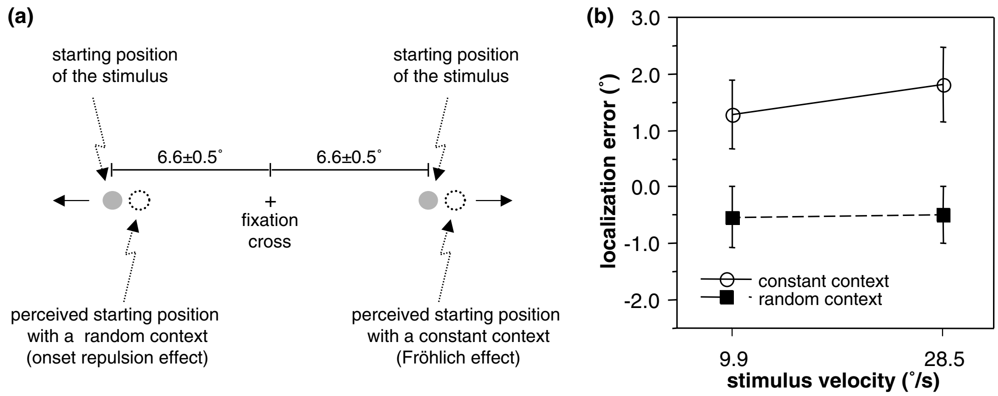

Fig. 1. (a) Stimulus presentation in the experiments. A moving stimulus appeared to the left or to the right of the fixation. Perceived starting positions were in the direction of motion in the Fröhlich effect and opposite the direction of motion in the onset repulsion effect. (b) Mean localization errors and standard errors of the mean (between observers) of the first position of a moving stimulus. Positive and negative values indicate errors in and opposite the direction of the motion, respectively.

of four directions (up, down, left or right). Therefore, the present experiments examine whether the conflicting localization errors might be caused by the different trial context.

1. Experiment 1

Localization performance was compared in identical trials set in either a 'constant context' in which target onset locations were predictable, and a 'random context' in which they were not.

1.1. Method

1.1.1. Apparatus and stimuli

The experiments were run on a Macintosh computer with Matlab using the Psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997). The stimuli were presented on a 20″ color monitor (75 Hz refresh rate, 1024×768 pix). The participant's head was placed on a chin rest 500 mm in front of the monitor. The stimuli were presented with a black-on-white projection with a monitor's luminance of about 37 cd/m^2. A gray disc of 0.7° visual angle with a luminance of 19 cd/m^2 was used as moving stimulus. Its onset position was $6.6 \pm 0.5°$ to the left or to the right of a central fixation cross and stimulus velocities were 9.9 and 28.5°/s (yielding presentation times of 734 and 254 ms). The trajectory length was always 7.2°.

Two context conditions were compared: In the constant-context condition, stimuli appeared always on the horizontal meridian to the left or to the right of fixation and moved away from the fovea (fugal motions). In the random-context condition, one sixth of the stimuli were as in the constant-context. In the remaining five sixth of the trials, the vertical and horizontal onset positions were random in a square of $30° \times 30°$ with the fixation cross in the center. In these trials horizontal direction of motion was random such that is fugal and petal motions were equally likely.

1.1.2. Design and procedure

The constant-context and random-context conditions were presented in separate blocks with the order of blocks counterbalanced across participants. Additionally, two velocities were varied yielding a 2×2 repeated measurement design.

The central fixation cross was visible throughout the experiment. Each trial began with an auditory warning signal and after 500 ms the stimulus appeared and moved to the left or to the right. The instruction stressed concentration on the fixation cross while the target moved. One second after stimulus presentation, subjects moved a cursor from its home position at the fixation cross to the position where they had perceived the beginning of the movement. The adjustment cursor was identical to the moving stimulus and was only visible in the adjustment phase.

During the adjustment phase of the cursor, observers were free to move their eyes. After having localized the perceived position, a mouse button press confirmed the adjustment and the next trial was initiated after a one second delay. All participants worked through 240 trials lasting about 75 min including the eye calibration procedure, a training block and a short break.

1.1.3. Monitoring of eye fixation

The horizontal position of the left eye was monitored with a head mounted and infrared light reflecting eye-tracking device (Skalar Medical B.V., IRIS Model 6500). If a saccade was detected during the presentation of the stimulus, the corresponding data were excluded from further analyses. The data of one participant were completely excluded because her mean exclusion rate deviated more than ±2 standard deviations from the corresponding mean of the sample. For the remaining participants mean exclusion rate was 8.7% in the constant-context condition and 9.5% in the random-context condition.

1.1.4. Participants

Ten individuals, aged 18–31 years, were paid to participate in the experiment. In the present and in the subsequent experiments all observers participated for the first time in a localization experiment and they reported having normal or corrected-to-normal vision.

2. Results and discussion

The difference between the adjusted and the true first position of the stimulus was computed. Positive and negative values indicate errors in and opposite the direction of the motion, respectively. Mean error values were computed for every observer and each condition separately.

As can be seen from Fig. 1(b), the constant-context condition produced a localization error of 1.54° ($s_e = 0.62$) in the direction of motion, while the random-context condition produced a localization error of −0.51 ($s_e = 0.50$) opposite to motion. The main effect of condition was significant in a 2×2 within-subjects analysis of variance (ANOVA) with $F(1,8) = 32.68$, $p < 0.001$. However, only the localization error in the direction of motion (the Fröhlich effect) was different from zero with $t(8) = 2.48$, $p < 0.05$, but not the localization error opposite to motion (ORE), $t(8) = 1.02$, n.s., always two-tailed. Thus, there was only a tendency in the means for ORE.

Stimulus velocity did not reach significance in the ANOVA. However, separate *t*-tests showed a difference in the localization errors in the constant-context condition, $t(8) = 2.82$, $p < 0.05$, but not in the random-context condition, $t < 1$. In other words, the experiment replicates the increase of the Fröhlich effect with increasing velocity (cf. Fröhlich, 1923; Müsseler & Aschersleben, 1998), but failed to show the velocity effect in ORE. Maybe the effect of velocity on onset repulsion is observed in a much slower regime of velocities (between 3 and 9°/s, cf. Thornton, 2002).

3. Experiment 2a and 2b

In Experiment 1, onset position (to the left/right of fixation) and motion direction (always fugal) were highly predictable in the constant-context condition. In contrast, both onset position and motion direction were unpredictable in the random-context condition. Thus, the differences between context conditions originated either from the spatial uncertainty or the directional uncertainty or both. To examine this possibility, we systematically varied spatial and directional uncertainty. Experiment 2a was a replication of Experiment 1, but target motions were always fugal. Thus there was directional certainty in both conditions, and spatial uncertainty only in the random-context condition. In Experiment 2b, the onset position was always to the left or right context of fixation (spatial certainty), but motion direction was always fugal in the constant-context condition and fugal or petal in the random-context condition. Taken together, the two experiments may show whether spatial or directional uncertainty is causing the difference between the two conditions.

3.1. Method

3.1.1. Stimuli and procedure

Two different random-context conditions were introduced: In Experiment 2a target motions were always fugal with onset positions random in a field of 30°×30°. In Experiment 2b, the onset position was always 8.5° ± 0.5° to the left or right of fixation (as in the constant-context condition), but motion direction was fugal or petal with equal probability. The constant-context conditions were as in Experiment 1, but target eccentricity was slightly increased in both conditions (6.5° in Experiment 1 vs. 8.5° in Experiment 2). The larger eccentricity prevented the target trajectories from passing through the fixation cross.

3.1.2. Participants

Nine observers participated in Experiment 2a (aged 20–43 years) as well as in Experiment 2b (aged 20–31 years). The constant-context and random-context conditions were presented in separate blocks with the order of blocks randomized across participants.

3.2. Results and discussion

As in Experiment 1, judgments in identical conditions were compared. The only difference was the trial context. With spatial uncertainty in the random-context condition (Experiment 2a), a localization error of 2.19° ($s_e = 0.52$) was observed in the constant-context condition and an error of 0.77° ($s_e = 0.38$) in the random-context condition with spatial uncertainty. The difference between conditions was significant with $t(8) = 5.19$, $p < 0.001$ and both errors were statistically different from zero with $t(8) = 4.24$, $p < 0.01$ and $t(8) = 2.03$, $p < 0.05$.

With directional uncertainty in the random-context condition (Experiment 2b), the localization error was 2.33° ($s_e = 0.51$) in the constant-context condition and 1.56° ($s_e = 0.51$) in the random-context condition with directional uncertainty. The difference between conditions was only marginally significant, $t(8) = 2.22$, $p = 0.057$, but both errors were different from zero with

$t(8) = 4.57$ and $t(8) = 3.07$, both $p < 0.01$. We may conclude that the localization error in motion direction is much more reduced with spatial uncertainty (Experiment 2a) than with directional uncertainty (Experiment 2b). Note, however, that localization errors were always positive. Thus a combination of both factors is more likely to produce the negative localization error (ORE).

4. Experiment 3

In Experiments 1 and 2, the stimuli always appeared at eccentric positions in the constant-context condition. In the random-context condition, however, stimuli occasionally appeared near fixation. One may assume that observers had a more accurate perception of onset position in these near-fixation trials (i.e., because of the high spatial resolution in the fovea). This may have helped observers to reduce any localization bias regardless of whether the stimuli were presented near fixation or not. In other words, it is possible that the localization judgments of the random-context condition generally benefited from the more accurate perception and localization in the near-fixation trials. If this was correct, the difference between conditions is expected to disappear in a random-context condition in which stimuli always appear at eccentric positions.

4.1. Method

4.1.1. Stimuli and procedure

The constant-context conditions were as in Experiment 1. In the random-context conditions target motions were always fugal with onset positions random in a field of $30° \times 30°$, but onset positions were not in the inner field of $10° \times 30°$ around central fixation. Thus, eccentricity of onset positions was at least 5° to the left or right of fixation.

4.1.2. Participants

Eight observers participated in the experiment (aged 20–28 years).

4.2. Results and discussion

Again, localization errors were larger in the constant-context condition than in the random-context condition. The mean localization error was 0.74° ($s_e = 0.20$) in the constant-context condition and −0.14° ($s_e = 0.30$) in the random-context condition. The difference between conditions was significant with $t(7) = 2.44$, $p < 0.05$, but only the localization error in direction of motion was different from zero with $t(7) = 3.70$, $p < 0.01$. We may conclude that a random-context condition, in which stimuli appeared always at eccentric positions, still produced much smaller localization errors than the constant-context condition. This is evidence that the difference between conditions originated from the spatial uncertainty independent of whether near-fixation trials were included in the random-context condition or not.

5. Experiment 4

In the previous experiments, the Fröhlich effect and ORE were observed within observers in successive blocks of trials even though the task was the same. This means that observers' responses changed within an experiment. If the effect of context took. hold immediately each new stimulus was presented, one could expect the changeover to be complete in a few trials. The present experiment examined the exact time course of this changeover.

5.1. Method

5.1.1. Stimuli, design and procedure

These were the same as in Experiment 1 save the following changes. Half of the observers were assigned to the constant-context condition, the other half to the random-context condition. Each participant was confronted with 100 trials. However, only every seventh trial, in which the stimulus always appeared at $6.6° \pm 0.5°$ to the left or right of fixation, entered the data analysis. As in Experiment 1, the constant-context and random-context condition differed only with regard to the trials presented in between.

Participants were verbally instructed at the beginning. Then, the experimenter demonstrated the procedure by performing a single trial. Data collection started with the first trial performed by the participants.

5.1.2. Participants

Forty-two fresh individuals, aged 20–35 years, were paid to participate in the experiment.

5.2. Results and discussion

The results are shown in Fig. 2. Note that the analysis was run with only a single observation for each combination of trial number, context and observer. The mean localization error was 1.60° ($s_e = 0.26$) in the constant-context condition and −0.20° ($s_e = 0.33$) in the random-context condition, but only the localization error in the constant-context condition was different from zero with $t(20) = 6.15$, $p < 0.01$. A 2×15 (context × trial number) ANOVA revealed a main effect of context, $F(1, 40) = 18.51$, $p < 0.001$, but no effects of trial number, $F(14, 560) = 1.28$, $p > 0.20$, and no interaction, $F(14, 560) = 1.34$, $p > 0.15$. However, when looking at the first five data points only, a corresponding 2×5

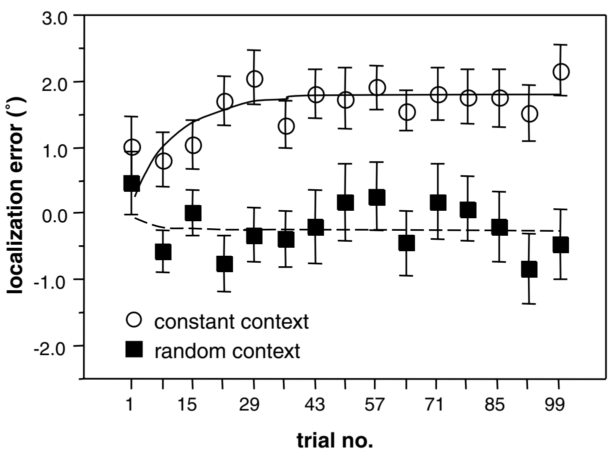

Fig. 2. Mean localization errors of the first position of a moving stimulus in the direction of the movement. Curves are fitted separately for each context condition to the exponential function $y = a \cdot \exp(-b \cdot x)$.

ANOVA revealed a significant main effect of condition, $F(1,40) = 19.85$, $p < 0.001$, and a significant interaction, $F(4,160) = 2.84$, $p < 0.05$. Separate comparisons of the first five group means by t-tests revealed significant differences between the random- and constant-context condition in the 22nd and 29th trial, at least ($p < 0.05$, at least, α-level Bonferroni corrected, two-tailed). Inspection of Fig. 2 suggests that the difference between conditions occurred somewhere in the region of the 15–35th trial.

6. General discussion

In four experiments, we demonstrated that the stimulus context strongly modulates localization of the first position of a moving target. When the target onset was highly predictable because the target always appeared close to two possible positions and moved only in a single direction, observers localized the target too far in the direction of motion (Fröhlich effect). In contrast, when the target onset was unpredictable because the target appeared at random positions within a large region of the display and moved in unpredictable directions, this localization error was at least drastically reduced. In fact, the mean localization error was in a direction opposite to target motion in three of four experiments, indicating a tendency for the onset repulsion effect (ORE). The difference between the two context conditions was reliable after only 22 trials.

These findings have far reaching consequences. Our results may either be taken to indicate that the perception of the onset position in a trial changes with the spatial predictability of the onset positions or that pointing movements are no reliable measure of perceived position. Possibly, pointing movements reflect perceived position in one condition, but not in the other. Alternatively, pointing movements may be an unreliable measure in general. So far, we have no means to evaluate these possibilities, but one may speculate about how predictability of target positions affected the pointing judgments.

With regard to ORE, Thornton (2002) systematically discussed five possible explanations. One of which may be applied to the difference between constant and random-context condition: When positional uncertainty is high, observers may notice a target relatively late, and with every new trial they might become aware of a possible localization error. To avoid this error, they may overcompensate and point to positions opposite to motion.

With predictable starting positions—as is the case in the constant-context condition (Fröhlich effect)—observers already know the approximate onset position of the target in advance. In this case, visual top-down mechanisms might play the critical role. It is known that sensorimotor behavior easily adapts to situations with predictable starting positions and motion directions. For instance, when a stationary target is displaced systematically with every onset of a saccade, an adaptive change of the saccadic amplitude is observed after only a few trials (e.g. Deubel, Wolf, & Hauske, 1986). The interesting open question is whether this adaptation affects only the motor system or whether it also exerts an influence on the perceptual system as indicated by the present results. Certainly, this problem needs further experimentation.

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